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То:	The City of Bay St. Louis
From:	Sai Kiran Duvvuri, P.E.
Date:	February 16, 2024
Subject:	Bay Saint Louis Municipal Harbor – Bulkhead Settlement – Inspection Findings and Recommendations
M&N Job No.:	230619

Introduction & Scope

At the request of the City of Bay St. Louis, M&N completed an above water condition assessment of the Bay St. Louis (BSL) Municipal Marina located on the Gulf Coast of Mississippi in June of 2023, specifically the concrete sheet pile bulkhead along the length of Pier 1 and the perimeter of the Event Deck and the pavement, but not the timber piers and walkways along the bulkhead's waterside face.

According to information provided by the city, the pavement adjacent to the bulkheads has experienced continuous settling over the years since the harbor's construction, despite previous repair efforts. The settlement varies along the length of the bulkhead, and localized demolition and coring of the pavement have uncovered voids or sinkholes beneath the settling pavement.

Moffat & Nichol (M&N) issued a memorandum dated September 29, 2023, detailing the inspection findings, probable causes, and suggested repair methods, along with associated costs. The repair methods proposed in the memorandum aimed to address the loss of fill behind the bulkhead along its entire length. For further details, please refer to Appendix A.

Recently, at the request of the city, alternative repair methods have been sought to address the areas of greatest settlement behind the wall. The aim is to reduce the overall cost of the proposed repairs, focusing on short-term solutions. This memorandum outlines two repair alternatives and compares their extents and costs to the original global repairs.

Repair Option A – Global Complete Repairs

The comprehensive repair solution involves excavating behind the entire length of the bulkhead wall to a depth of 1 foot below the waterside mudline. This excavation allows for the placement of geofabric behind all sheet pile joints before backfilling and repaving. Additionally, groundwater pressure relief weep holes will be installed in every other sheet pile. For more detailed information, please refer to the "Preliminary Bulkhead Repairs and Probable Cost" section in Appendix A

The estimated total cost for this repair effort was \$2,150,000.

Repair Option B – Targeted Complete Repairs + Slab Jacking

This option involves implementing the same complete repair procedures as Option A, but with a focus on specific locations where significant loss of fill has occurred. These locations are defined as areas with voids below core holes, with over a foot of easily penetrated soils beneath the bottom void. Out of the 12 cored pavement locations observed during the June 2023 assessment, 10 are considered significant and will be targeted for repair.

For the remaining length of the bulkhead outside of the designated repair areas, the pavement will be raised back to its original elevation using foam injection, also known as slab jacking. The height of the jacking will be equal to the current settlement, with the average settlement measured by M&N during the assessment being 1.8 inches.

The estimated total cost for this repair effort is \$1,053,000.

Sinkhole Repairs (Excavation/Geofabric)**	\$753,000*
Bulkhead Drainage (Weep Holes)	\$75,000*
Settlement Repairs (Slab Jacking)	\$75,000*
Total Cost	\$1,053,000*

Table 1: Probable Cost of Repairs

*All costs include a 30% contingency for preliminary estimates of cost.

**Sinkhole repair cost assumes that contractor will excavate at a 1H:1V slope for temporary excavation in granular backfill.

Repair Option C – Targeted Limited Repairs + Slab Jacking

This option involves targeted repair at a specific location where critical voids exist below the pavement, while slab jacking is employed elsewhere. The targeted repair includes localized pavement demolition, backfilling of voids with sand (without excavation), and subsequent repaying. It's important to note that this option does not address sealing the bulkhead joints below.

The critical location identified is approximately 130 feet north of the southwest corner of the bulkhead (Station 2+60 in M&N's field alignment), as indicated in the figure below. At this location, the bottom of the void was found to be 2 feet and 3 inches below the bottom of the pavement. During investigation, M&N inserted a steel rod used for soil probing 6 feet into the soils below the void without encountering resistance, indicating ongoing loss below the current void depth. Additionally, the concrete pavement immediately behind the bulkhead was observed to have cracked through its full width.



Figure 1: Location of Critical Voids



Figure 2: Critical Void Location - Pavement Cracking

The estimated total cost for this repair effort is \$327,000.

Table 2. Frobable Cost of Repairs		
Sinkhole Repairs (Backfilling)**	\$44,000*	
Settlement Repairs (Slab Jacking)	\$283,000*	
Total Cost	\$327,000*	
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Table 2: Probable Cost of Repairs

*All costs include a 30% contingency for preliminary estimates of cost.

**Sinkhole repair cost assumes that the soft soils below the void will settle under the weight of backfill and double the current void fill quantity.

Note that this effort prioritizes cost reduction by abstaining from endeavors to temporarily prevent future loss of fill behind the bulkhead. While it restores pavement to its original grade, it's important to anticipate potential future loss of fill and settlement.

Comparison of Repair Alternatives

Costs & Design Life

The costs of the (3) alternatives are summarized below.

Option A – Global Complete Repairs	\$2,150,000*
Option B – Targeted Complete Repairs + Slab Jacking	\$1,053,000*
Repair Option C – Targeted Limited Repairs + Slab Jacking	\$327,000*

*All costs include a 30% contingency for preliminary estimates of cost.

Cost: Option A is the only choice that effectively prevents future loss of fill through the potential failure modes identified in the September 2023 Assessment and Recommendations memo, covering the entire length of the bulkhead. However, this naturally results in the highest total cost.

Design Life: M&N acknowledges the City's request for a design life for the repairs. The design life of Option A, being a comprehensive repair, will be as long as the existing bulkhead remains structurally sound. However, M&N's examination of the marina record drawings did not uncover any reference to the bulkhead's design life. Therefore, the City would need to locate the Basis of Design documentation for the original project.

Cost: Option B addresses loss of fill for the same modes, but only at existing locations of significant loss, as indicated by core holes in the pavement during M&N's June 2023 assessment. It does not, however, protect against future loss at other locations. M&N's assessment revealed pavement settlement across the entire length of the bulkhead, suggesting that other areas will continue to experience loss of fill, albeit at a slower rate than current significant loss locations.

Design Life: The complete repair areas offer comprehensive protection against loss of fill along an assumed 12-foot-long strip centered on each sinkhole. Geotextile fabric will be installed to cover the bulkhead joints, extending up the side slopes of each excavation. However, the joints' height below the slopes remains unprotected. Consequently, while the significant loss of fill locations will be addressed, the repairs will have a very limited impact beyond the actual sinkhole location.

Slab jacking does not have a reducing effect on future loss of fill. The rate of loss of fill cannot be accurately estimated due to the pavement concealing the true extent of the voids below. Assuming that the significant locations are addressed by the targeted repairs, a rough estimate of the rate of future settlement can be made. The highest observed settlement away from the significant locations was 1.5 inches. The marina was constructed between 2013-2014 based on Google Earth footage. Therefore, the rate of settlement can be estimated as 1.5 inches per 10 years, resulting in 0.15 inches per year at the non-significant locations.

The City can establish a functional "design life" for the slab jacking by determining the acceptable level of settlement before additional future repairs or jacking are necessary. Furthermore, they can utilize the settlement rate to calculate the timeframe until the next repairs are required.

Cost: Option C restores the pavement to its original grade, filling voids below with sand or foam injection, but does not include any measures to halt loss of fill. It represents the least expensive option, but global loss of fill will persist, with current significant loss locations experiencing faster loss than the rest of the bulkhead.

Design Life: As this option does not prevent loss of fill, including at significant locations, the estimated settlement rate will be higher. The highest settlement at significant locations was 4 inches, which would result in a rate of 4 inches per 10 years, equivalent to 0.4 inches per year at these locations. Similar to Option B, the City can establish a "design life" until the next repairs using this rate and determining the acceptable level of settlement.

Recommendations

M&N strongly recommends repair option A as it offers a comprehensive solution to fix the sinkhole issue once and for all along the entire length of the bulkhead. However, if funding for this option is an issue, then at the very least, Option B should be considered. Option B targets permanent fixes but only at the known problem locations. Additionally, Option B can be viewed as a phased approach to the full repairs, with known critical areas addressed in Phase I. Future repairs can then be performed for the rest of the bulkhead to prevent similar issues along the unrepaired locations in Phase II. M&N is committed to developing design solutions for the repairs as directed by the City.

APPENDIX A – September 2023 Assessment and Recommendations Memo